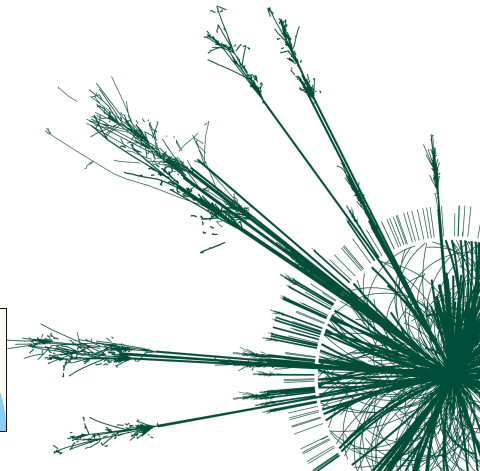


Brookhaven Forum 2021

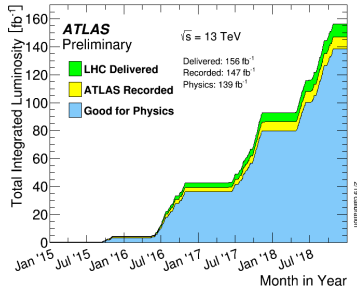
Search Highlights **ATLAS + CMS**

Jochen Jens Heinrich for the ATLAS and CMS collaborations

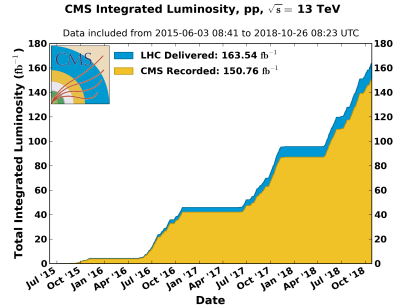
03 November 2021



The Run 2 datasets



- Extremely successful Run 2
 - 94% data taking efficiency
 - 95% data quality fraction
- ⇒ More than 139 fb^{-1} of pp data to analyse



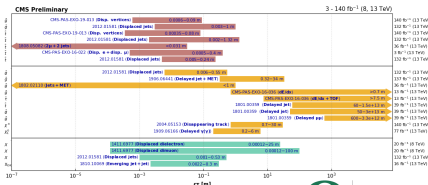
- Extremely successful Run 2
 - 92% data taking efficiency
 - 91% data quality fraction
- ⇒ More than 137 fb^{-1} of pp data to analyse

ATLAS Preliminary
 Conf. no. 1001.011 5. 10. 2014

*Only a selection of the available mass limits on new states or phenomena is shown

ATLAS Preliminary

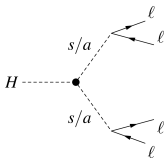
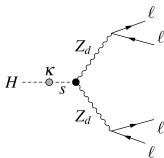
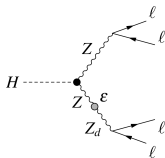
40200 GHz \rightarrow 2.2	low-CMP 16-400 jets, MS \rightarrow 30.1	3.000 nm	0.41-0.15 nm	$r \times S = 1 \mu\text{m}$, $\omega(\lambda) = 50^\circ\text{NAy}$	1902.02094
40200 GHz \rightarrow 2.2	low-CMP 16-400 jets, MS \rightarrow 30.1	3.000 nm	0.09213 nm	$r \times S = 1 \mu\text{m}$, $\omega(\lambda) = 50^\circ\text{NAy}$	1902.02094



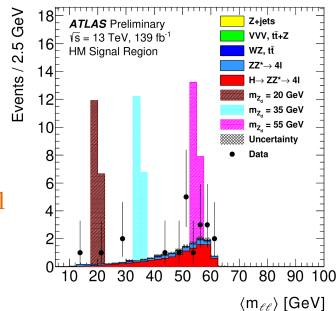
Higgs boson decays to new spin-0 or spin-1 particles

ATLAS-CONF-2021-034

- Due to narrow H width even small BSM couplings can result in measureable branching fractions
- Existing precision measurements still allow up to 19% of Higgs decays to undetected (See: ATLAS-CONF-2020-027)
- Search for Higgs decay to **new spin-0 or spin-1 particles** in 4-lepton final states where $l = e, \mu$
- New bosons with masses between 1 and 60 GeV have been investigated



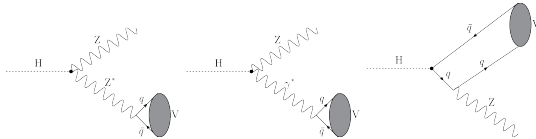
- The data are found to be **consistent with predicted Standard Model** backgrounds
- Limits on $\mathcal{B}(H \rightarrow Z_d Z_d)$ as low as $2\text{--}8 \times 10^{-5}$



Higgs boson decays into Z and ρ or ϕ meson

CMS-HIG-19-012

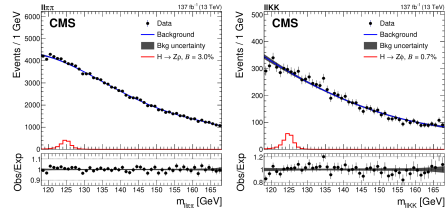
- Have not yet reached required sensitivity to measure Yukawa couplings to second or first generation fermions
- Yukawa couplings to light fermions accessible via rare exclusive decays, e.g. $\gamma J/\psi$, $\gamma\rho$, $\gamma\phi$ (limits 2 orders larger than SM) $\gamma\psi(2S)$ (3), $\gamma Y(nS)$ (5) [arXiv:1810.10056](https://arxiv.org/abs/1810.10056), [arXiv:1807.00802](https://arxiv.org/abs/1807.00802), [arXiv:1712.02758](https://arxiv.org/abs/1712.02758)
- For the first time searched for Higgs decays to $Z\rho$ and $Z\phi$



- Z required to decay to two leptons ($l = e, \mu$), ρ and ϕ to pair of pions or kaons
- Upper limits on Higgs branching fraction (depending on polarisation scenario):

$Z\rho$ 1.04 – 1.31% (740-940 times SM exp.)

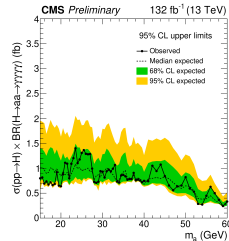
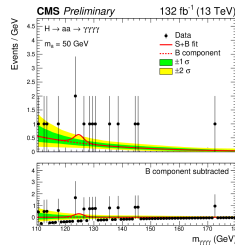
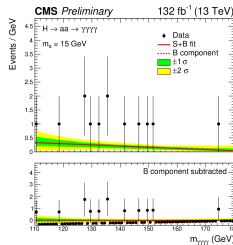
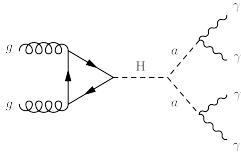
$Z\phi$ 0.31 – 0.40% (730-950 times SM exp.)



Search for decays to two pseudoscalars in the 4γ final state

CMS-PAS-HIG-21-003

- Current limits allow for up to 40% of the Higgs branching fraction to BSM states
- Considering models with $15 < m_a < 60$ GeV with four isolated photons in the final state
- MVA relying on the perceived pseudoscalar mass is used to optimise sensitivity
- Perform a maximum likelihood fit of the signal and background models in the 4γ distribution

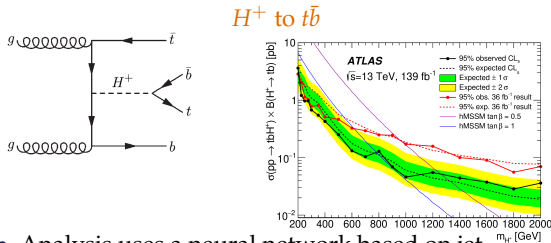


- No excess of events observed
- Observed (expected) limits range from 0.80 (1.00) fb at $m_a = 15$ GeV to 0.33 (0.30) fb for $m_a = 60$ GeV

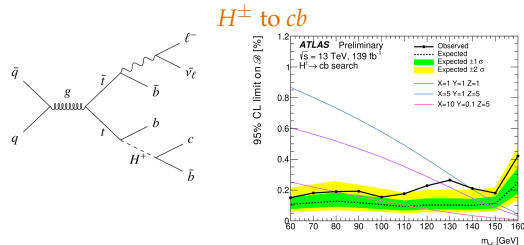
ATLAS searches for charged Higgs bosons

[arXiv:2102.10076](#), [ATLAS-CONF-2021-037](#)

- Extended Higgs sectors with additional doublets or triplets result in charged Higgs bosons
- ATLAS published several searches for charged Higgs bosons in various decay channels (also see [ATLAS-CONF-2021-047](#) for $H^\pm \rightarrow W^\pm \mu \mu$)



- Analysis uses a neural network based on jet multiplicities and various kinematic variables combined with fit to data
- No excess observed and limits are set

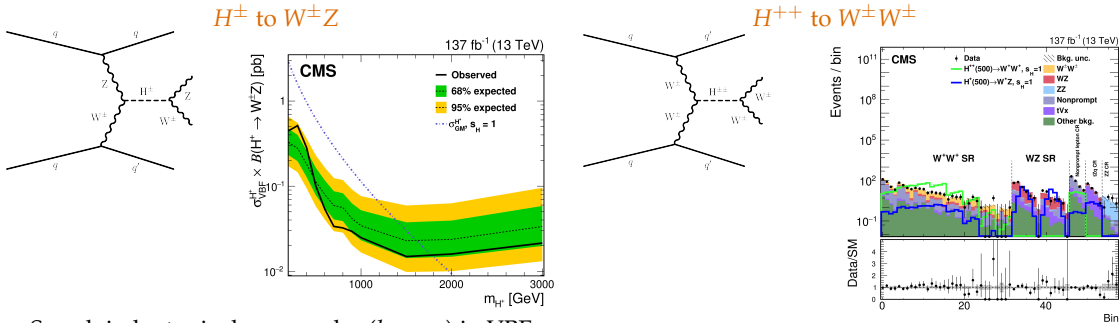


- Charged Higgs production in top-quark decays
- Use high multiplicity of b -jets
- A neural network is used to discriminate signal and background
- No excess observed

CMS searches for charged Higgs bosons

[arXiv:2104.04762](https://arxiv.org/abs/2104.04762)

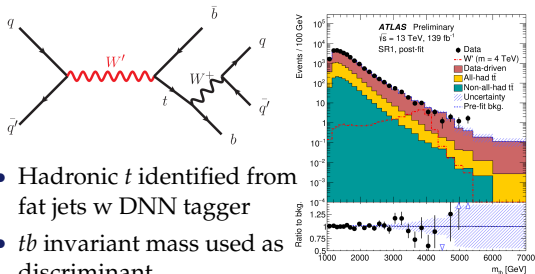
- CMS recently published a search for single- and double-charged Higgs bosons to dibosons



- Search in leptonic decay modes ($l = e, \mu$) in VBF processes
- Binned maximum likelihood fit simultaneously to WW and WZ spectra using transverse mass and dijet invariant mass
- No excess observed and results interpreted in Georgi-Machacek model (most stringent limits to date)

ATLAS heavy resonance searches

- Multiple BSM theories predict **new gauge bosons** on the TeV scale to address the hierarchy problem
- Search for **right-handed leptophobic W'** with same coupling strength as SM W

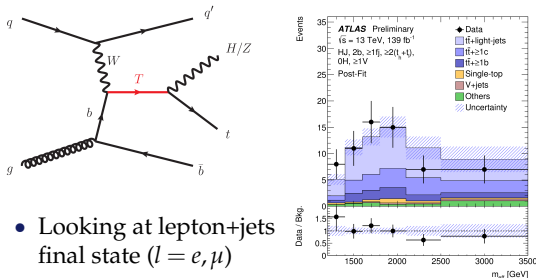


- Hadronic t identified from fat jets w DNN tagger
- $t\bar{b}$ invariant mass used as discriminant
- Data-driven background estimate
- W' with **masses < 4.4 TeV** (4.1 TeV exp.) **excluded**
- See also [CMS-PAS-B2G-20-005](#)

JJ Heinrich
Slide 9/17

ATLAS-CONF-2021-040, ATLAS-CONF-2021-043

- Search for **up-type vector-like quarks** with $T \rightarrow Ht/Zt$ where $H \rightarrow b\bar{b}$, $Z \rightarrow q\bar{q}$



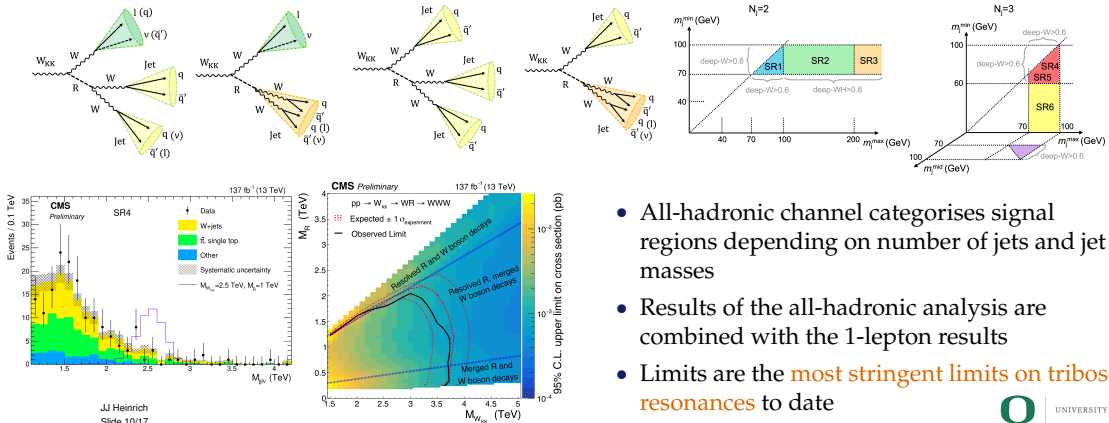
- Looking at lepton+jets final state ($l = e, \mu$)
- Selection on $m_{eff} = \sum p_{T,i} + E_T^{miss}$
- T **masses below 1.8 TeV** (1.5 TeV exp.) are **excluded** for couplings $\kappa \geq 0.5$
- See also [CMS-PAS-B2G-19-004](#)



Resonances into three W bosons

CMS-PAS-B2G-20-001, CMS-PAS-B2G-21-002

- Search for models with massive **Kaluza-Klein W's** decaying to scalar radions
- Separate publications for 1-lepton and all-hadronic final states
- Have radion decays collimated into one or two large-R jets

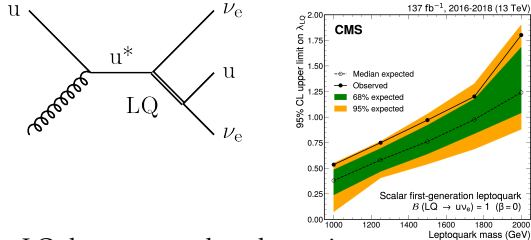


- All-hadronic channel categorises signal regions depending on number of jets and jet masses
- Results of the all-hadronic analysis are combined with the 1-lepton results
- Limits are the **most stringent limits on triboson resonances** to date

Searches for Leptoquarks (LQ)

- LQ are hypothetical particles that carry baryon and lepton numbers
- Multiple searches published by ATLAS and CMS, e.g.: [ATL-PHYS-PUB-2021-017](#), [CMS-EXO-19-015](#)

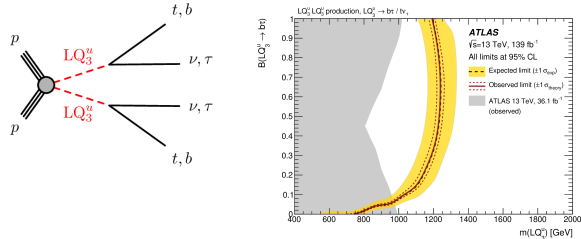
CMS high- p_T jets + MET



- LQ decay to quark and neutrino
- Alternatively LQ can be produced in pairs, but high- p_T jet + MET sinature remains
- Use joint maximum likelihood fit in SR and CR to constrain backgrounds

[CMS-EXO-20-004](#), [ATLAS-SUSY-2019-18](#)

ATLAS τ + b -jet + MET



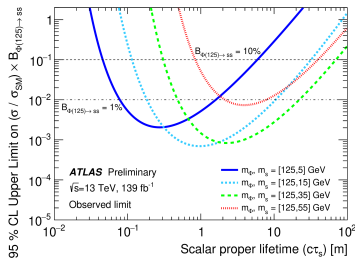
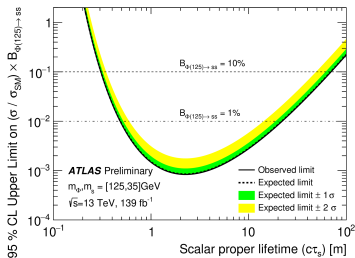
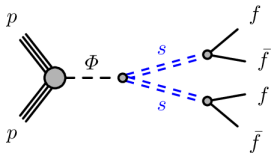
- Consider LQ with charge $\frac{2}{3}e$ and $-\frac{1}{3}e$
- LQ decay only to 3rd-generation SM particles
- Search in single-tau channel

\Rightarrow Data are found to be consistent with SM expectation

Displaced vertices (DV) from neutral particles

ATLAS-CONF-2021-032

- Higgs portal/Hidden sector/SUSY models predict Higgs decays to **long-lived particles decaying to jets**

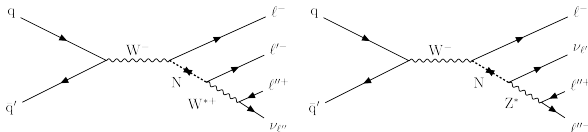


- Use a dedicated Muon RoI Cluster trigger, reconstruct tracks and DV in Muon Spectrometer
- Require DV to be isolated from jets and tracks to suppress punch-through jets
- Background estimated with **data-driven method**
- No events** with two DVs are found with an expected background of 0.32 ± 0.05
- For SM-like Higgs branching ratios above 10% are excluded for proper lifetimes 4 cm to 71.3 m
- See also a corresponding search from CMS at [CMS-EXO-19-013](#)

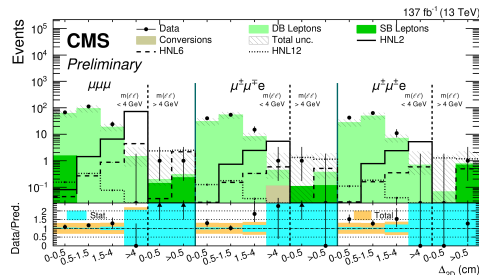
Long-lived heavy neutral leptons (HNLs)

CMS-PAS-EXO-20-009

- HNLs could give an explanation for **small neutrino masses, dark matter and baryon asymmetry**
- HNL is assumed to be a Majorana neutrino that **violates lepton number** (Dirac particles also possible)
- Low SM background for signatures with no opposite-sign, same-flavour leptons ($e^\pm e^\pm \mu^\mp$ or $\mu^\pm \mu^\pm e^\mp$)



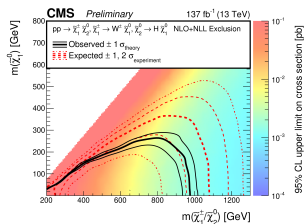
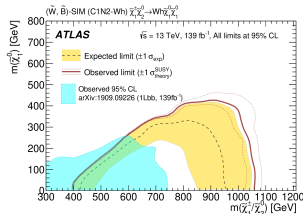
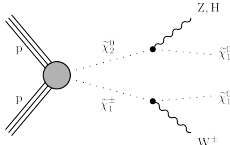
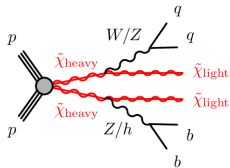
- Depending on mixing parameter and for small HNL masses (< 20 GeV) the HNL can have **long lifetimes**
- Search for three-lepton events with two originating in DV and the third prompt
- Background is estimated with data-driven techniques
- Derived **best limits to date on this type of search**



Electroweak SUSY production

ATLAS-SUSY-2018-41, CMS-PAS-SUS-21-002

- Electroweakinos with masses 0.1 – 1 TeV address **dark matter, hierarchy problem, muon $g - 2$ anomaly**
- Assume strongly-coupled sparticles too heavy \rightarrow search for electroweak production
- LSP escapes detector, thus signature is **WH , WZ or WW plus large momentum imbalance**
- ATLAS and CMS recently published updated searches in the all-hadronic channel

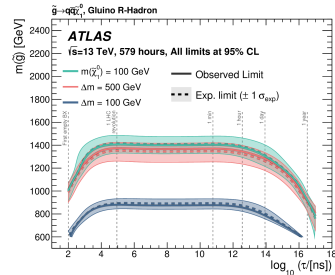
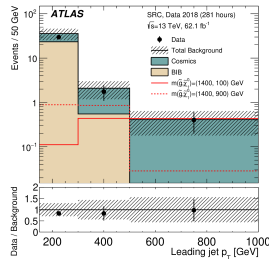
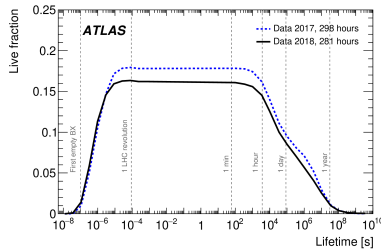


- ATLAS targets mass-splitting > 400 GeV between LSP and NLSP
- Use boosted-boson-tagging techniques (ATLAS: reclustered jets, CMS: DNNs) to reconstruct W, Z and H and suppress background
- **No excesses**, set limits are comparable between experiments

Stopped long-lived particles

ATLAS-SUSY-2018-15

- Heavy long-lived particles traverse the detector slowly and **might be stopped** in the detector
- Decay leaves significant energy deposits significantly later (depending on τ) than production BC
- Search looks in **"empty"** BCs with cosmics and beam-induced backgrounds as backgrounds
- Analysis is sensitive to a huge **lifetime range between 10^{-5} and 10^3 seconds**

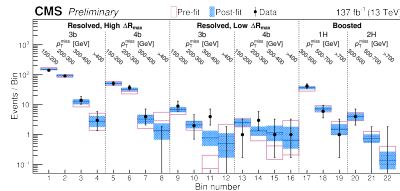
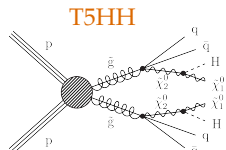
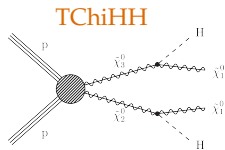
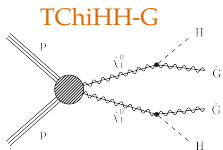


- Use dedicated empty BC triggers with $E_T^{\text{miss}} > 50$ GeV and at least one jet with $p_T > 55$ GeV
- **First ATLAS limit at $\sqrt{s} = 13$ TeV** and excluded gluinos < 1.4 TeV for $\tilde{\chi}_1^0 = 100$ GeV

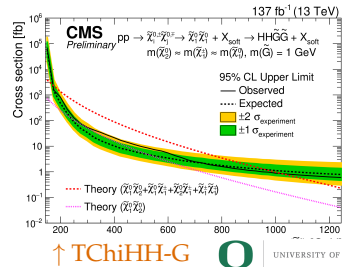
Higgsinos in HH(4b)+MET final states

CMS-PAS-SUS-20-004

- Search is designed for sensitivity to **several scenarios** of SUSY particle production
- Can have intermediate SUSY particles contributing to final state, but always have $HH \rightarrow b\bar{b}b\bar{b} + \text{MET}$



- Looked separately at resolved region and boosted region to reconstruct Higgs
- Use an ABCD method to predict SM backgrounds, SRs defined according to p_T^{miss} and N_{bjets}
- Small excess (global: 1.9σ) in one bin
- In T5HH model **gluino masses < 2330 GeV are excluded**



Conclusions

- ATLAS and CMS had a **highly successful Run 2**
- Roll-out of new results based on the full Run 2 dataset is peaking at the moment
- Both experiments have very **similar sensitivities**
- All searches reported here show no significant deviation from SM expectation
- Continuing to **push limits and sensitivities to unprecedented values**

BACKUP MATERIAL